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Assessing the sustainability challenges for electricity industries in ASEAN newly industrialising countries

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A B S T R A C T

Rapid social and economic progress in fast developing countries such that among the countries in the Association of Southeast Asian Nations (ASEAN) have driven substantial growth in electricity consumption in this region. Whilst this represents significant societal and economic development, it has potentially growing adverse environmental impacts. This raises a concern on sustainable development in the electricity sector in this region. This study evaluates key sustainability challenges in the electricity industries in the five largest energy consumers in ASEAN: Indonesia, Thailand, Malaysia, the Philippines and Vietnam. The 3A's energy sustainability objectives: *Accessibility*, *Availability* and *Acceptability* are used as the sustainability analytical framework. This study also draws together a set of associated indicators and criteria within the analytical framework to analyse the status of the electricity industries in these countries. The analysis shows that key sustainability challenges in the ASEAN-5 are attributable to satisfying rapid demand growth; enhancing security of electricity supply; and mitigating the increase in CO_2 emissions from electricity generation. Given the promising resource and technical potential in this region, renewable energy emerges as a favourable option to address these challenges; however, increasing the share of renewable energy in electricity generation requires considerable policy support. This study suggests that there is an opportunity for the ASEAN countries to strengthen regional collaborations through experience and resource sharing to enhance sustainability in the electricity industries. This study also highlights some of the key issues facing the electricity industry, and the need for new generation investment decision support tools which can address these issues.

Contents

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1. Introduction

Sustainable development, as defined by the Brundtland Commission, is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs."[1]. There are continuing debates about the concept and its usefulness, including questions of whether sustainable development refers to a desirable destination or, instead, process towards such a destination [2]. It has also proved a difficult concept to apply in practice, and its use in the area of energy is no exception. What is clear is that energy sustainability has vital social, economic and environmental dimensions. In terms of social sustainability, energy is a basic human need and access to reliable and affordable energy sources can greatly improve our quality of life. With regard to sustainability's economic dimension, energy availability is a key driver in the economic growth and development prospects of a country. Of particular relevance to this paper, access to modern energy services, including electricity, at an affordable price is widely agreed to be essential for poverty eradication and economic development within developing countries [3]. Environmentally, the world's present energy systems are the primary drivers of some of our greatest environmental challenges including, of course, climate change.

The electricity sector is currently the largest single contributor to global greenhouse emissions due to its heavy reliance on fossil fuels, primarily coal and gas [4]. CO_2 represents the most significant greenhouse gas, and the electricity sector produced around 40% of global CO_2 emissions in 2007, having risen from 27% in 1971. Furthermore, CO_2 emissions per capita for the electricity sector increased by 82% during the same period due largely to increased electricity access and growth in electricity infrastructure, especially in fast developing countries [4]. It is apparent that the electricity sector presents a considerable sustainability challenge given its significant role in both socioeconomic development yet also environmental deterioration. A key question, then, is whether future development of the electricity sector can be done in a way that is consistent with our sustainability objectives – that is to ensure adequate and affordable access to modern energy in an economically viable, socially and environmental acceptable manner. This is particularly important in fast developing countries in which the emphasis is, understandably, often on economic growth [5].

The region of the Association of Southeast Asian Nations (ASEAN)[1] is one of the fastest developing regions in the world [6]. This region has also been identified as likely to play an increasing important role in future world energy demand over the next few decades due to its rapid economic expansion and large population size. Rapid economic growth and social development have major energy implications since they are the main driver of energy consumption [7]. The electricity sector is also predicted to be the major source of growth in CO_2 emissions in ASEAN [8].

The importance of this region for our global energy future has been acknowledged by the International Energy Agency (IEA) as reflected in a recent World Energy Outlook report [8], which provides an analysis of the energy situation in ASEAN. However, the assessment of electricity sectors in this region in the context of sustainability (social, economic and environment) has, in our view, been largely overlooked by energy researchers and analysts despite its important role in socioeconomic development.

The underlying motivation for this work is the significant economic, social and environmental implications of the electricity industry that are not always well integrated into policy making for the sector. In part this problem would seem to result from a lack of appreciation of some of these implications. Importantly, many are externalities – that is costs and benefits for stakeholders that are not directly transferred within the electricity industry itself. In part, also, the problem seems to be one measurement – it is easy to talk about environmental sustainability of the industry in general terms but policy can be facilitated by quantified assessments and associated targets. As such, sustainability assessments of the electricity sector can play a valuable role in assisting policy makers to better understand both existing and emerging sustainability issues within the sector, and options in addressing them.

There are a number of studies which analyse sustainable development within the energy sector based on a set of measurable energy indicators in various countries and regions such as Taiwan [9], Brazil [10], the Baltic Sea Region [11,12], India [5], the European Union [13], Cuba, Mexico, Slovakia and Thailand [14]. In addition, there are other studies which employ the concept of energy and sustainability indicators to explore various energy-related issues including: using as a planning tool for assisting energy planning at local level [15]; and assessing renewable energy and conventional technologies [16,17]. However, such studies to date generally do not focus on the sustainability in the context of the electricity sector or address the broad range of relevant sustainability aspects within the sector. As for the ASEAN region, the existing literature related to the electricity development in this region has focussed primarily on issues related to economic development or environmental challenges [18,19].

The aim of this study is to apply a sustainability analytical framework to identify and evaluate key sustainability challenges for the electricity industries in five selected ASEAN countries: Indonesia, Thailand, Malaysia, the Philippines and Vietnam. These countries are referred to as the ASEAN-5 in this study. These countries are

[1] The Association of Southeast Asian Nations (ASEAN) comprises ten countries: Brunei Darussalam, Cambodia, Indonesia, Laos DPR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam.

selected for this study because they are the five largest electricity-consuming countries in ASEAN, accounting for around 90% of ASEAN total electricity consumption [20]. Furthermore these countries possess similarities in terms of their geographical location, social and economic contexts, and this permits a meaningful cross-country analysis to be carried out. The cross-country comparison is intended to support benchmarking of the performance, policy effectiveness and emerging issues within the electricity sector of each country. Furthermore, energy policy making is influenced by both national and regional contexts. A cross-country comparison may also help policy makers to identify opportunities for greater collaboration and integration among the countries of the region in addressing their shared and different sustainability challenges. This study is also intended to provide an initial framework that can guide policy making towards improved sustainability in the electricity sectors of the ASEAN-5. This work does not explicitly offer policy recommendations. Rather, the study provides some insights and preliminary thoughts on emerging sustainability challenges and issues that need to be considered in policy making for the region.

This work contributes to the existing literature in the area of energy sustainability assessment in several ways. Firstly, it provides a sustainability assessment framework that draws together a set of relevant indicators and criteria in the context of the electricity industry. Secondly, this study operationalises the framework to evaluate sustainability challenges for electricity industries in the ASEAN region by bringing together relevant data from a wide range of sources across these five countries. These aspects have not been brought together in this way in previous works.

This paper is organised as follows: in Section 2 we briefly outline the wider social and economic context, and the electricity demand situation of the ASEAN-5 countries. The detail of the energy sustainability framework is described in Section 3. Section 4 presents a sustainability analysis of the electricity industries of the ASEAN-5. Key sustainability challenges in electricity industries of these countries are summarised in Section 5 and followed by conclusions in Section 6.

2. Social and economic context for electricity industries in the ASEAN-5

This section presents some key social and economic context for the countries in the ASEAN-5 that has significant implications for their electricity industries. An overview of the electricity industries in the ASEAN-5 is also provided in this section.[2]

2.1. Socioeconomic development and implications for the electricity industries

Key social and economic development and their implications for electricity industries in the ASEAN-5 can be summarised below. Specific details and figures of social and economic data of the ASEAN-5 are shown in Appendix.

- **Significant populations and rapid population growth** – the ASEAN-5 have a combined population of nearly 500 million people [8,21]. During the past 20 years, populations in these five countries have increased between 20–40% compared to 12% in the OECD [21]. Such growth adds to the challenges of delivering electricity-based energy services to the community to keep up with increasing population. It also suggests that indicators in per capita terms are more meaningful than absolute terms in understanding societal welfare in these countries.
- **Increased urbanisation** – urbanisation in these five countries has increased rapidly since 1990, but is still comparatively lower than the OECD [22]. The increase in urbanisation should assist in improving electricity access since it is considerably easier and less costly to electrify urban than non-urban populations. However, these countries still have significant non-urban populations to support and the transition involves potentially difficult reallocations of resources. Increased access also drives electricity consumption, adding to the challenges noted above.
- **Improving human development** – every country in the ASEAN-5 is classified in the medium human development category, except Malaysia which is in the high development category [22]. The Human Development Index (HDI)[3] in these countries has also been improving over the past two decades. There is a clear association between electricity consumption and HDI since access to electricity helps to improve quality of life. Generally, countries with higher HDI have higher per capita electricity consumption (albeit with some significant complexities in this relationship) and it has been argued that the HDI of developing countries cannot increase without an increase in electricity consumption [23].
- **High GDP growth** – countries in the ASEAN-5 have all achieved robust economic growth over recent decades due largely to increases in trade and foreign investment [24]. Since the late 1990s, these five countries have been able to maintain economic growth at around 4–8% per year. GDP growth has significant implications for electricity demand growth.
- **Generally significant level of Foreign Direct Investment (FDI)** – FDI is a major source of investment fund in developing countries, including the electricity sector. Such FDI depends, of course, on the investment environment within these countries. It is also arguably accompanied by the transfer of technology and managerial know-how [25]. On-going development of the ASEAN-5 electricity industries is likely to require continued success in attracting FDI.
- **Increasing per capita income** – per capita income growth rate in the ASEAN-5 is on a rising trend, and higher than the average growth attained in the OECD [26]. The increase in per capita income implies higher spending power, which potentially leads to an increase in desired and affordable modern energy services implying, in turn, growing electricity consumption.
- **Increasing industry sector value added in GDP** – the share of GDP from the industry sector for every ASEAN-5 country, except the Philippines, is greater than 40% compared to around 25% for OECD countries [26]. Again with the exception of the Philippines, industry sector value added in each country has been increasing as a proportion of total GDP, at the expense of agriculture and service sectors. This contribution of industry sector value added to GDP indicates that these countries are continuing to industrialise [14]. This trend suggests a structural change of the ASEAN-5 economies, which traditionally are agricultural-based economies, towards industrialisation which is typically more energy intensive than other sectors, leading again to an increase in electricity consumption. This is in contrast with OECD countries which, in many cases, have declining industry sectors. There are significant implications for energy consumption and

[2] Data related with the electricity sectors in this section largely reflects arrangements of interconnected or relatively large island grids. Whilst significant numbers of people in some countries of the ASEAN-5 are not connected to these large grids and obtain their electricity services from small diesel grids or stand-alone systems, obtaining reliable data on this is particularly challenging.

[3] The Human Development Index (HDI) is a composite index developed by the United Nations to measure average achievement in three dimensions of human development which are a long and healthy life, access to knowledge and a decent standard of living [22].

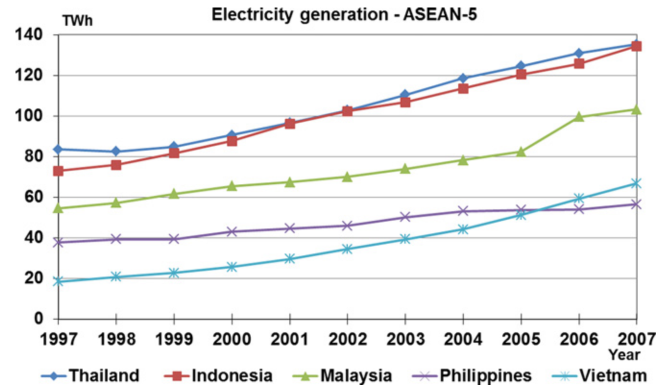

Fig. 1. Electricity generation during 1997–2007. Data source: EIA [29].

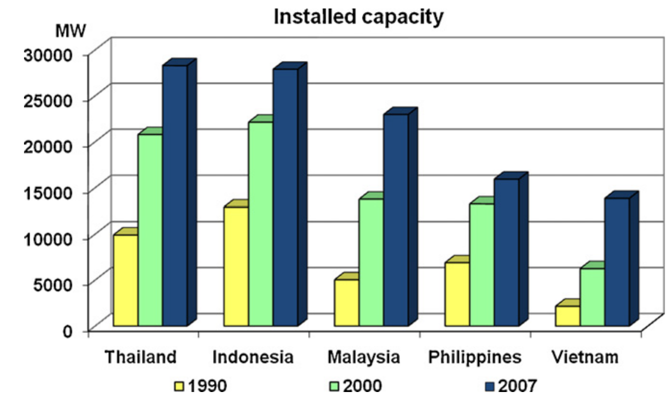

Fig. 2. Installed generation capacity between 1990 and 2007. Data source: EIA [29].

greenhouse emissions in the transition of manufacturing from developed to fast growing developing countries.

In summary, countries in the ASEAN-5 share some important similarities in terms of social and economic context by comparison with OECD averages. The ASEAN-5 can be characterised by relatively high population growth, rapid urbanisation albeit with significant proportions of the population still living outside towns, high economic growth, a high and growing contribution of industry sector value added to GDP, generally significant levels of FDI, and recent substantial increases in per capita income. There is also evidence that the ASEAN-5 is moving towards industrialisation. These key factors are tightly linked to electricity demand since in developing countries, increasing population, urbanisation, economic growth and rapid industrialisation constitute the major factors of growth in electricity demand [27].

2.2. The electricity industries in ASEAN-5

The structure of the electricity industries in the ASEAN-5, except for the Philippines, are still vertically integrated under a single buyer model in which state-owned utilities are responsible for electricity generation, transmission and distribution. Independent Power Producers (IPP) are also allowed to sell electricity to the grid under Power Purchase Agreement (PPA) arrangements in which state-owned utilities act as a sole buyer [28]. Decision making in the electricity industries in the ASEAN-5 countries is generally conducted under relatively centralised and only moderately transparent governance arrangements.

Fig. 1 shows that electricity generation in the ASEAN-5 countries has increased significantly since the late 1990s, ranging between 50 and 300%.

Such increases in electricity generation have led to considerable additions of generation capacity in these countries as shown in Fig. 2. The generation capacity in the ASEAN-5 countries has increased about three fold in less than 20 years. This growth rate, if continued, implies that the electricity industries in the ASEAN-5 have to double their generation capacity every 10 years. This situation clearly presents significant implications for sustainability in the electricity industries in these countries.

Beyond the social and economic risks of failing to meet the growing energy service needs of the countries, lies growing challenges in environmental impacts and energy security. Fig. 3 shows that the electricity sector in the ASEAN-5 countries contributes on average between 30 and 40% of total national greenhouse emissions [4]. This paper is particularly intended to help better understand these challenges through a quantitative framework based on the 3A's sustainability objectives framework.

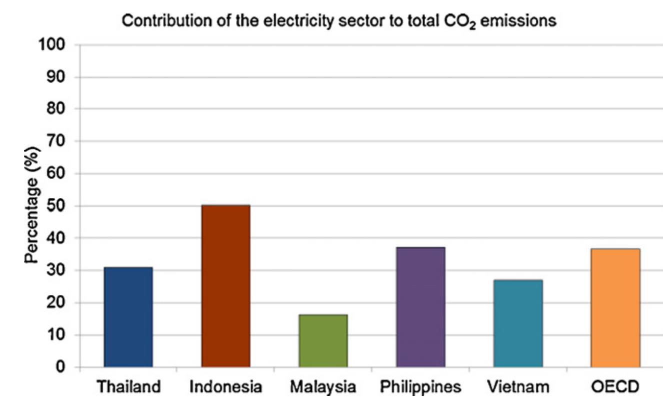

Fig. 3. Contribution of the electricity sector in total CO_2 emissions in 2007. Data source: IEA [4].

3. 3A's energy sustainability framework

The sustainability analytical framework employed in this study is based on the 3A's energy sustainability objectives introduced by the World Energy Council (WEC). The 3A's energy objectives[4] comprise of three aspects: *Accessibility*, *Availability*, *Acceptability* [31]. These aspects are explained in the context of the electricity industry in Section 3.1. The 3A's energy objectives framework addresses social, economic and environmental dimensions, which are the underlying principles of sustainability, in a manner particularly suitable for assessing energy industries. This study also draws together a set of associated indicators and criteria to assess each aspect of the 3A's energy objectives in the context of electricity industries in the ASEAN-5. The selected indicators and criteria are explained in Section 3.2.

3.1. Energy sustainability objectives

- *Accessibility* – is defined to be the provision of modern energy services at socially affordable prices in a sustainable manner for all. Electricity access can improve social status by facilitating provision of human basic needs such as health, food and education [32]. A particular challenge is posed by the concept of affordability in this context. Clearly, people have to be able to afford essential energy services. However, it has also been argued that prices within the electricity sector should reflect the true value of energy services and costs of electricity production,

[4] The WEC has recently included another challenge to this framework, which is Accountability. This framework is now known as the 4As [30].

transmissions and distribution, including externality benefits and costs of the industry, such as the environmental harms of greenhouse gas emissions. In theory, it is such prices that will drive efficient industry operational and investment decisions that maximise societal benefit [31,33]. This tension will be explored further later in the paper.

- *Availability* – this aspect covers short-term quality of service and long-term continuity of electricity supply [31]. The continuity of electricity supply is essential for social and economic development of the country. Unreliable electricity supply can arise from a wide range of issues. In the short-term, key issues include insufficient generation and network capacity to meet demand perhaps arising from inefficient plants, poor maintenance or other factors such as extreme weather events. In the longer-term, additional issues arise such as the availability of fuel sources such as coal and gas. A reasonably well-diversified generation portfolio of different technologies and fuel types and sources can mitigate energy security risks [31,34]. Furthermore, this aspect requires adequate and timely investment in the electricity infrastructure to ensure the continuity of supply [35]. The consequences of failing to maintain continuity of electricity supply can cost as high as 1–2% of GDP in some countries [36].
- *Acceptability* – this aspect relates to social and environmental sustainability in the electricity industry. Public involvement is seen as a means to improve social acceptability [37], as are decision making processes that are open and transparent [33]. This is especially the case for new large-scale power projects, and particularly nuclear power. Social concerns regarding nuclear security have, indeed, opened up decision making processes for greater public and stakeholder involvement [37,38]. In terms of environmental acceptability, climate change is almost certainly the most serious longer-term environmental threat arising from the present electricity sector [39]. Various generation technologies can also have other adverse health and environmental impacts including regional air pollution associated with fuel combustion, and land-use change from options such as large-scale hydro. It has been suggested that clean technologies and their transfer to developing countries is the key to attain environmental sustainability [31].

The relationship and evident trade-offs between the 3A's objectives are interconnected. Ideally, addressing one aspect of the 3As should not hinder progress towards the other remaining aspects. However, it has been argued that addressing basic needs, which include energy access and energy security, should take higher priority than social and environmental acceptability particularly in developing countries [40].

3.2. Sustainability indicators and criteria for assessing the 3A's energy objectives

This study draws together a set of carefully chosen quantitative indicators and qualitative criteria, with a focus on the electricity industry in the context of the ASEAN-5, to assess each aspect of the 3A's energy sustainability objectives. Although there is no common or standardised rule for choosing indicators, the main selection criteria is the ability to address important energy issues of the country and help to assess the effectiveness of energy policies [14].

Key quantitative indicators used in this study are drawn based on the Indicators for Sustainable Energy Development (ISED) framework which aims to provide a deeper understanding for relationships between energy, environment and economic nexus as well as tracking the progress towards sustainable energy development goals in each country [41,42]. The ISED framework was developed by the International Atomic Energy Agency (IAEA) to address important issues in three major dimensions of sustainability: economic, social and environment in the energy sector.

The selected indicators are adapted to suit each aspect of the 3A's energy objectives framework and the context of electricity industries in the ASEAN-5. Apart from the indicators based on the ISED, additional quantitative indicators and qualitative criteria which focus specifically on the electricity industry are also derived. Main issues and criteria for the indicators are that they must be measurable, and measured in a way that guides policy decision-making in the context of the ASEAN-5. More importantly these indicators must illustrate interconnections in order to link the three aspects of the 3A's energy objectives.

The challenge of the data set used in this study lies mainly in its continued and rapid changes over social, economic and energy indicators. For each indicator, we have attempted to use the data from the same sources for every country in order to provide accurate cross-country comparisons.

3.2.1. Accessibility indicators and criteria

Accessibility is related to the access to electricity at affordable prices in a sustainable manner. The quantitative indicators chosen to assess the accessibility aspect consist of electrification rate, electricity tariff, average expenditure on electricity bills, per capita electricity consumption and growth, and electricity intensity (the ratio of electricity consumption to economic output).

The qualitative criterion considered for this aspect is the issue of electricity tariff subsidies, since this aspect relates to sustainable electricity pricing. Subsidies have been used by many countries around the world as one of the approaches to accelerate electricity access among lower income groups. However the subsidy burden can lead to deficits in the national budget [36]. Non-cost reflective tariffs can also create price distortions since it may lead to inappropriate end-user and supply decision making. It has also been argued that subsidies may hinder infrastructure development in the electricity sector since utilities are unable to obtain the revenues needed for new investment [8]. Energy subsidies are an extremely complex and controversial issue, which involves social and economic dimensions. Given this issue is not the main focus of this study, we only presents potential implications relating to subsidies in the context of the ASEAN-5.

3.2.2. Availability indicators and criteria

Availability reflects the energy security aspect, which can be categorised into short-term reliability and long-term continuity of electricity supply.

a. Indicators for short-term reliability of supply. Short-term reliability of supply involves the generation, transmission and distribution of electricity to end-users. Due to the complex nature of reliability, several indicators are needed to determine the extent of supply reliability [43]. The indicators selected for this aspect include the System Average Interruption Frequency Index (SAIFI), the System Average Interruption Duration Index (SAIDI) and system reserve margin.

SAIFI and SAIDI are commonly used to measure the reliability of the grid over a given time period [43]. SAIFI measures the average number of times during a year that a customer is interrupted, and is defined as

$$\text{SAIFI} = \frac{\text{total number of customers interrupted}}{\text{the average number of customers served}} \quad (1)$$

SAIDI measures the average duration of interruptions in minutes or in hours per customer during the year. This index is a measure

Table 1
Summary of indicators for each of the energy sustainability objectives.

3A's energy objectives	Dimension	Indicators and criteria
Accessibility	Affordable price	1. Electricity prices ($)
		2. Average expenditure on electricity bills (% of income)
		3. Electricity tariff subsidy (checklist)
	Energy services	4. Electrification rate (%)
		5. Electricity intensity (kWh/GDP)
		6. Electricity consumption per capita (kWh)
Availability	Short-term reliability of supply	7. Reserve Margin (%)
		8. SAIFI (no. of times), SAIDI (min)
		9. Reliability operating standards (checklist)
		10. Cross-border supply and interconnections (checklist)
	Long-term continuity of supply	11. Fuel mix in electricity generation (% share of each fuel type)
		12. Reliance on imported fuels for electricity generation (%)
		13. Fuel diversity (Shannon–Wiener Index)
Acceptability	Safety	14. Strategy for nuclear power (checklist)
	Greenhouse emissions	15. Renewable energy policy (checklist)
		16. Share of renewable energy in electricity generation (%)
		17. CO_2 emission per capita (tCO_2)
		18. CO_2 intensity in terms of economic and electricity output

of the response or restoration time when outages occur. SAIDI is defined as

$$\text{SAIDI} = \frac{\text{the sum of all customer interruption durations}}{\text{total number of customers served}} \tag{2}$$

SAIFI and SAIDI together provide a suitable measure of the reliability of electricity supply as they capture key features of the range of power interruptions experienced by end users [44].

Reserve margin is an indicator for measuring the amount of spare generation capacity above the peak demand. This criteria has been used as relative indication of system adequacy [45]. Reserve margin is expressed as

$$\text{Reserve margin (\%)} = \frac{\text{total installed capacity} - \text{peak demand}}{\text{peak demand}} \tag{3}$$

Other qualitative criteria for assessing short-term reliability of supply are the reliability operating standards and the existence of cross-border interconnections. The reliability operating standards may include a standard operating practice such as the N-1 security criteria,[5] system frequency and voltage standards. These criteria determine the ability of electricity systems to withstand disturbances and contingencies, which resulted from unanticipated loss of system elements such as transmission lines or generating units. The presence of cross-border interconnections can enhance the reliability of electricity systems in addition to reducing investment and operation costs [46].

b. Indicators for long-term continuity of supply. For long-term security of electricity supply, the chosen indicators and criteria are related to the shares of fuel mix in electricity generation, and the reliance on imported fuel for electricity generation. Fuel mix captures the balance of fuel types in electricity generation in a country's generation portfolio. Over-dependence on particular types of fuels can have serious potential consequences for long-term continuity of supply. As such, fuel mix is a useful indicator in assessing availability since it can be used as a basis to measure diversity and possible long-term security of electricity supply [31]. Diversifying energy resources can reduce the risks arising from fuel price fluctuations as well as physical supply interruption. Diversity is, however, a potentially complex concept with respect to energy security where issues include fuel type, fuel sources by geographic regions or supplier, or technology types [47]. Domestic availability of particular energy sources is also relevant, as are potential issues regarding whether there is active or potential export of these fuels as an alternative to the domestic market. This study focusses on diversity in fuel types for electricity generation. The Shannon–Wiener Index (SWI) can be used as a quantifiable indicator to measure diversity. SWI is one the most useful concentration indices where higher values of SWI imply greater diversity [48]. SWI is mathematically expressed as

$$H = -\sum_i p_i \cdot \ln p_i \tag{4}$$

where p_i is the proportion of electricity generation from fuel source i.

3.2.3. Acceptability indicators and criteria

Indicators and criteria selected for this aspect are mostly related, either directly or indirectly, to CO_2 emissions from the electricity sector since CO_2 represents the most significant anthropogenic greenhouse gas, and the electricity sector is the largest source of CO_2 emissions worldwide [4].

There are also other potential local environmental impacts relating to water, land-use, and other atmospheric pollutants such as SO_2, NOx and particulate matter (PM) caused by fossil (and potentially biomass) fuel-fired electricity generation. Although such pollutants can have significant adverse impacts on human health, they are not considered in this study. In part, this choice reflects the main focus of our study which is on cross-country comparison. These local and regional issues are very context specific within as well as between the countries being studied. This choice also arises from constraints on our study length and resources. Finally, for some of these issues there are relatively straightforward and effective ways to significantly reduce their impact such as, for example, controlling SO_2, NOx and PM from power plants through a combination of combustion measures and pollution control systems using Electrostatic Precipitators (ESP) and Flue Gas Desulphurisation (FGD) [49]. Such measures and equipment are already being used in some of the ASEAN-5 countries. Furthermore ASEAN countries already have in place some forms of environmental regulations that set permissible limits on SO_2, NOx and PM from power plants [50]. This is not to argue that these regional air pollutants are now being well managed and no longer a cause for concern. Adverse health impacts continued to be experienced in the ASEAN-5 countries and elsewhere around the world (including many OECD countries). There are potentially significant costs

[5] The N-1 security criterion is a requirement that the power system can withstand the loss of any single component of an electricity supply system such as a generating unit or transmission network equipment.

associated with reducing these emissions and other potential trade-offs such as power plant output. However, the policy challenge posed by climate change is very different – there are no straightforward technical fixes for existing fossil-fuel plant to achieve major emission reductions.

The quantitative indicators employed in this study for the environmental aspect include CO_2 emissions per capita and CO_2 intensity both in terms of economic output (CO_2/GDP) and electricity generation (CO_2/kWh). The CO_2 intensity of electricity generation depends largely on fuel types that are used to generate electricity and, in particular, on the share of low and non-emitting sources such as gas, hydro, nuclear, and renewable energy in the generation mix [51]. The share of renewable generation capacity is also considered in order to determine the progress of renewable-based electricity generation in these countries. Furthermore, it can be used to improve our understanding of the relationship between emissions and the penetration of renewable electricity generation in different countries.

Strategy for nuclear power and renewable energy (RE) policies are also considered since they have direct environmental and social acceptability implications. RE policy is seen as a key driver in the growth of renewable-based electricity generation in all but a few countries given the typically low direct costs of fossil fuels. The strategy for nuclear power and related regulatory framework has a direct implication on social acceptability due to public concerns over nuclear security in many ASEAN countries.

Carbon and capture storage (CCS) technology is another potential option for mitigating CO_2 emissions from the electricity sector. However, there are a number of regulatory and economic issues that need to be addressed before large-scale commercial deployment of CCS. Incorporating CCS in a power plant may increase the generation cost by 40–65% [52]. Furthermore, limited CO_2 storage potential and technical challenges among the ASEAN-5 present major barriers for CCS development in this region [53]. Therefore the potential role of CCS is not discussed in the analysis.

Table 1 provides a summary of indicators and criteria for each aspect the 3A's energy sustainability objectives.

4. Sustainability assessment in electricity industries in the ASEAN-5

The indicators and criteria described in Section 3 have been applied to electricity industries in the ASEAN-5 to illustrate the application of the framework, and provide insights into the sustainability challenges of the region. Note that not all of the proposed indicators and criteria are actually used due to some current gaps in available information for the ASEAN-5 countries. These indicators include the average expenditure on electricity bills, SAIFI and SAIDI in some countries, and the reliability operating standards. These indicators could, if and when available, improve our understanding of the sustainability challenges.

4.1. Accessibility

Electricity access in all five countries has been improving over the past decades with Thailand and Malaysia being able to provide nearly 100% electricity access. These countries also continue to progress towards providing electricity access to their rural populations. Table 2 shows the electrification rate of each ASEAN-5 country in 2008.

Urban electrification rates in all five countries are fairly high with Indonesia being the lowest at 94%. Indonesia and Philippines have the lowest rural electrification rates of 32 and 65%, respectively. There are geographical barriers issues in both Indonesia and the Philippines since these two countries contain large numbers of islands, making it difficult to implement cost effective large-scale grid systems. In OECD countries, of course, electrification is basically 100% across and urban and rural populations. Rural electrification should be a key priority for Indonesia and Philippines in order to alleviate poverty and support economic growth.

Table 2
Electricity access in 2008.

Country	Electrification rate (%)		
	Total	Urban	Rural
Thailand	99.3	100	99.0
Indonesia	64.5	94.0	32.0
Malaysia	99.4	100	98.0
Philippines	86.0	97.0	65.0
Vietnam	89.0	99.6	85.0

Source: IEA [8].

Table 3
Average residential electricity tariff in 2005.

Country	Electricity tariffs ($US/kWh)
Thailand	0.072
Indonesia	0.058
Malaysia	0.071
Philippines	0.073
Vietnam	0.07
OECD	0.124

Sources: ASEAN Centre for Energy [54], IEA[55].

Table 3 shows the average electricity tariffs for residential consumers in these five countries in 2005. Every country, with the exception of Philippines, provides subsidies for electricity prices, particularly Indonesia [27] as reflected by its relatively low electricity tariffs compared with other ASEAN member countries. All of the countries' tariffs are also low by comparison with the OECD.

Subsidies can have significant adverse effects – they require government revenue to be directed away from other possible uses, or involve a revenue shortfall to the electricity industry utilities which can prevent them from undertaking necessary investment to increase their generation capacity and networks [31]. For example, non-cost reflective tariffs in Indonesia are a major factor hindering generation investment and resulting in supply shortages [56]. Although the purpose of subsidised electricity tariffs has historically been to increase electricity affordability, especially for the poor, it needs to be arranged in a manner that would not prevent the utility to obtain sufficient revenue to maintain its services, or prevent governments from providing other key services.

Electricity consumption per capita and the electricity consumption growth rate during 1990–2007 are shown in Figs. 4 and 5,

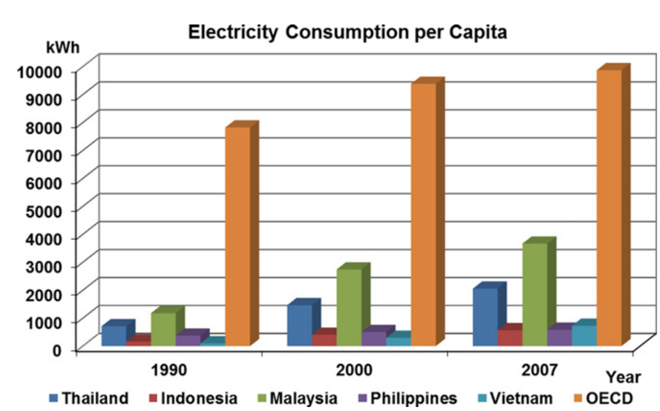

Fig. 4. Per capita electricity consumption.
Data source: World Bank [26].

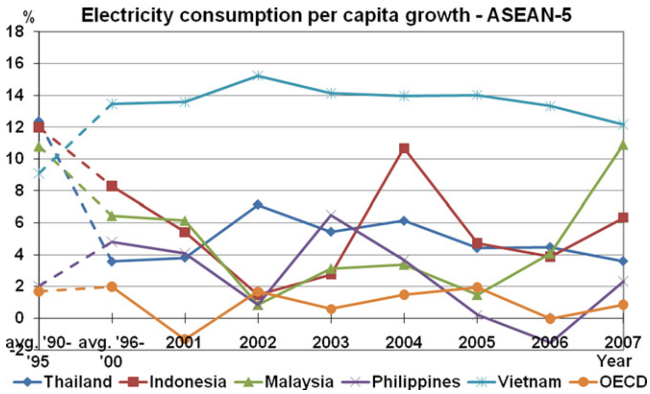

Fig. 5. Electricity consumption per capita growth rate.
Data source: World Bank [26].

respectively. The electricity consumption per capita of countries in the ASEAN-5 is still well below the OECD. However, the consumption growth rate is considerably higher than that of the OECD average due to the numerous drivers noted in Section 2. Vietnam has the highest growth in electricity consumption averaging around 15% due mainly to its strong economic growth. In 1990, per capita electricity consumption in Vietnam was the lowest among these five countries but its per capita consumption in 2007 exceeded those of Indonesia and the Philippines.

Fig. 6 shows the electricity intensity per unit of GDP adjusted 2005 purchasing price parity (PPP) US dollars.

Generally, the trend of electricity intensity among ASEAN-5 is on the rise, which implies that electricity consumption growth has outpaced economic growth. This is opposite to the OECD average in which the electricity intensity has been declining. During 1990–2000, the increase in electricity intensity in all five countries is more significant compared with the increase during 2000–2007. Between 1990 and 2000, electricity intensity in these countries increased between 30 and 90% but during 2000–2007 the rate of increase has slowed down to about 10%, with the exception of Vietnam. These variations in electricity intensity can have numerous drivers including changes in energy efficiency, the structure of the economy, and the penetration and the utilisation of electricity equipment and appliances [14]. The nature of the change in electricity intensity can be determined by decomposing it into sectoral electricity intensity to isolate the effect of changes in the economy structure. However such analysis is beyond the scope of this study. In this case, the increase in electricity intensity is likely due to the shift in economic structure from agriculture and services to industry sector as stated in Section 2.1. Furthermore, it is likely

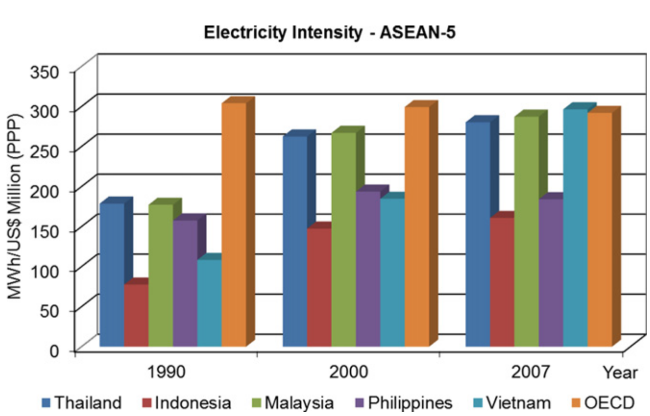

Fig. 6. Electricity intensity per unit of GDP.
Source: World Bank [26].

Table 4
Reserve margin and cross-border interconnections in the ASEAN-5.

Country	Reserve margin (%)	Interconnections
Thailand	25	Malaysia and Laos PDR
Indonesia	Deficit	–
Malaysia	40	Thailand and Singapore
Philippines	30	–
Vietnam	25	China, Laos PDR and Cambodia

Sources: IEA[56], EGAT[57], TNB[58], ADB[59], and AESIEAP[60].

due to higher electricity access as well as greater penetrations of electricity appliances.

It appears that these countries are making progress in terms of accessibility. Higher electricity consumption implies, other factors being equal, greater affordability and accessibility [14]. If the information on the proportion of household expenditure on electricity bills were available, we would be able to gauge and compare the affordability among these countries. In some countries such as Indonesia, the Philippines and, perhaps, Vietnam, further improvement is still required to increase electricity access in rural areas. One of the major issues facing these countries is the arrangements of tariff subsidies since it could potentially prevent electricity utilities from making necessary investments due to revenue shortages.

4.2. Availability

The availability aspect relates to energy security in both short term and long term. It has been shown in previous section that these five countries have experienced strong electricity consumption growth over the past two decades. This poses a challenge in terms of maintaining adequate and reliable electricity supply on a continuous basis to meet the electricity demand requirement.

4.2.1. Short-term reliability of supply

Unlike Thailand and Vietnam, power grids in Indonesia, the Philippines and Malaysia are fragmented into many areas due to their geographies therefore the analysis for the short-term reliability of supply is focussed on what considered to be the main grid of these three countries, which are Java-Bali in Indonesia, Luzon in the Philippines and the Malaysia Peninsular.

Reserve margins of the ASEAN-5 are shown in Table 4. Typical reserve margin targets are normally in the range of 18–25% [46]. Every country except Indonesia has a relatively high reserve margin, which is between 25 and 40%. Although a high reserve margin such that in Malaysia arguably improves the reliability of supply, it incurs additional costs resulting in an increase in the overall generation cost that might be avoided without adverse impacts on reliability. Indonesia has negligible reserve margin due to generation shortages as a result of rapid increased demand and under investment in the power sector as mentioned in the previous section.

Among the ASEAN-5, Thailand, Malaysia and Vietnam have cross-border interconnections with neighbouring countries whereas Indonesia and the Philippines do not have such interconnections due to their isolated geographical locations. Cross-border interconnections can help to enhance the reliability and security of the electricity supply, particularly during periods of high demand.

SAIFI and SAIDI for both transmission and distribution levels in these five countries are shown in Table 5. For Indonesia and Thailand, SAIFI and SAIDI for the distribution levels are further categorised into metropolitan and provincial areas while Malaysia has only one SAIFI and SAIDI figure for the distribution level. The information provided in Table 5 reflects the most recent data that is publically available (either 2007 or 2008). Due to the lack of data, we could not obtain SAIFI and SAIDI at both transmission and distribution levels for Vietnam.

Table 5
SAIFI and SAIDI of transmission and distribution systems in the ASEAN-5.

Country	Transmission level		Distribution level			
	SAIFI	SAIDI (min/year)	SAIFI		SAIDI (min/year)	
			Metropolitan	Provincial	Metropolitan	Provincial
Thailand	0.35	8.258	2.3[a]	9.57[b]	50.65[a]	385.93[b]
Indonesia	Not available		6[c]	13[d]	332[c]	530[d]
Malaysia	0.287	6.6	0.83		78	
Philippines	0.63	45	Not available			
Vietnam	Not available		Not available			

Sources: EGAT[57], MEA [61], PEA[62], ADB [63], TNB[58], and The Japan Economic Research Institute [64].
[a] Distribution network in Bangkok and Metropolitan areas.
[b] Distribution network in provincial areas outside Bangkok and Metropolitan areas.
[c] Distribution network in Jakarta and Tangernang.
[d] Distribution network in Central Java.

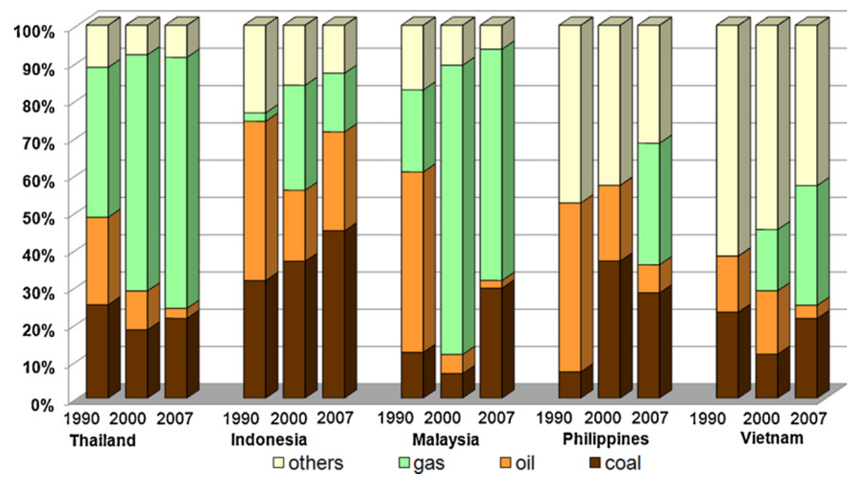

Fig. 7. Fuel mix trend 1990–2007 in electricity generation.

Data source: IEA [67].

Although methods of recording interruptions may differ among electric utilities, industry surveys generally find that typical values of SAIFI and SAIDI at distribution level are between 0.95 and 1.7 interruptions per customer and 90 and 150 min in a given year, respectively [65,66].

The interruption indexes at the transmission level for Thailand, Malaysia and the Philippines are relatively low which indicates reliable transmission networks. This corresponds with a fairly high reserve margin in these countries as shown in Table 5. SAIFI and SAIDI for the transmission network are not only influenced by generation reserve margin but also network reserve such as the available capacity of transmission network elements.

At the distribution levels, however, only Malaysia can be viewed as having reliable distribution networks. The interruption indexes for the distribution levels in the provincial areas of both Thailand and Indonesia are very high, suggesting that distribution networks in rural areas in these two countries are not very reliable. It also indicates that consumers in provincial areas experience far more frequent interruptions and longer restoration times compared with those within urban areas. Among these countries, Indonesia has the poorest supply reliability. Negligible reserve margins in Indonesia have led to a considerable amount of unserved demand and is one of the key reasons that contributed to its high interruption indexes compared with other countries.

4.2.2. Long-term continuity of electricity supply

Some key long-term continuity of supply challenges for the ASEAN-5 can be gauged from the trend of fuel mix in electricity generation.

Fig. 7 shows the fuel mix in electricity generation in the ASEAN-5 during 1990–2007. Generally, the use of natural gas for electricity generation has considerably increased over the past two decades and it has become the preferred fuel source in all countries with the exception of Indonesia. Thailand and Malaysia depend heavily on natural gas for electricity generation, accounting for more than 60% of the total electricity generation in 2007. The concern over energy security due to a heavy reliance of natural gas has resulted in a recent increase in coal-fired electricity generation particularly in Thailand and Malaysia. The share of coal fluctuated around 20–40% during 1990–2007. Indonesia has the largest share of coal in electricity generation and the share of coal has increased from 30% in 1990 to 45% in 2007. Whilst coal is a lower priced fuel with lower price volatility, this development does work against progress on managing greenhouse emissions and hence environmental acceptability which will be discussed further in the next section.

Fig. 8 illustrates the detailed fuel mix in electricity generation in 2007 for the ASEAN-5 compared with five OECD countries: Australia, the USA, the UK, Japan and France. It highlights that the 'Other' fuel sources indicated in Fig. 7 are largely hydro generation.

Indonesia, the Philippines and Vietnam appear to have a relatively well diversified fuel mixes. However, the fuel mix in Indonesia comprises of a considerable share of oil which potentially adversely affects energy security due to its price volatility and growing availability concerns. In Vietnam, the majority of electricity supply is from hydropower, which accounts for nearly 40% of the total generation. Whilst an excellent electricity generation option, this could also pose a problem during the dry season, since hydro plants are often unable to operate at their full capacity at

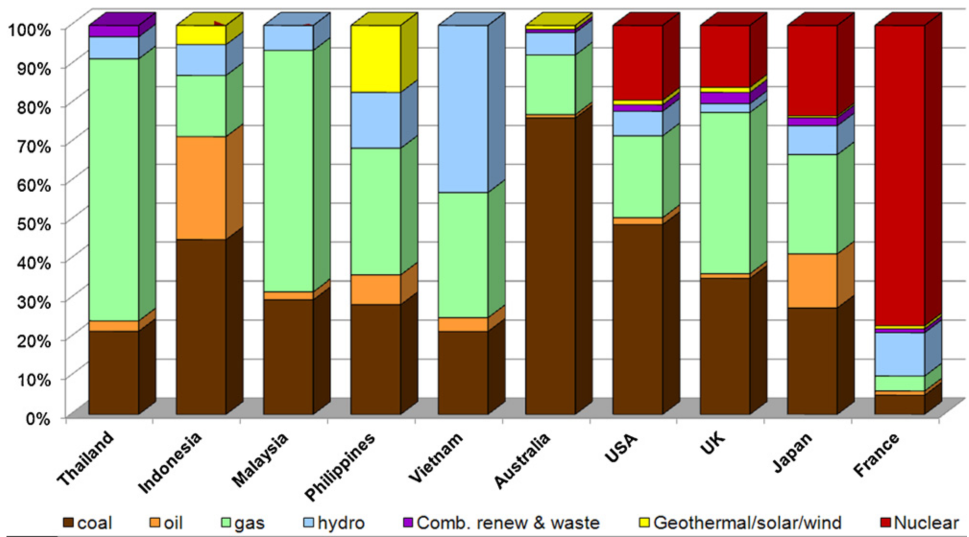

Fig. 8. Fuel mix in electricity generation in 2007.

Data source: IEA [67].

such times. The Philippines and Indonesia have significant potential in geothermal power, ranking second and third, respectively, in the world in terms of geothermal generation capacity [39]. In 2007, the share of geothermal power in Indonesia and Philippines was 5% and 17%, respectively.

Fuel diversity in the electricity generation sector is quantitatively measured using the Shannon–Wiener Index (SWI). Fig. 9 shows the SWI for the ASEAN-5 as well as the five selected OECD countries. It has been suggested that a value of below 1.0 indicates that the system is highly concentrated and could threaten security of electricity supply. A value above 2.0 implies a system with numerous sources [47].

Thailand and Malaysia have the lowest SWI, which are below 1.0 indicating that the electricity generation is highly dependent on a particular type of fuel, which is natural gas. On the other hand, the SWI for Indonesia, the Philippines and Vietnam is around 1.2 which indicates more diversified fuel mixes. Among the five selected OECD countries, France and Australia have the lowest SWI due to their heavy dependence on nuclear and coal for electricity generation, respectively. Japan has a well-diversified fuel mix with similar proportion of coal, gas and nuclear, as reflected by its relatively high SWI. Although higher SWI indicates greater fuel diversity, it does not necessarily imply greater energy security since the SWI does not reflect other aspects which also affect energy security such as fuel types in the generation mix. As noted above, for example, the ready availability of relatively low-cost coal from a range of countries might suggest high energy security value (although we revisit this in the next section).

Thailand and Malaysia rely heavily on natural gas and their fuel mixes are rather concentrated. This could have significant energy security implications in the long run due to the exposure to risk from fuel supply availability and price fluctuation. Although the majority of natural gas supplies are currently sourced domestically, natural gas prices in both Thailand and Malaysia are highly dependent on international prices through indexation with fuel oil in the Singapore market [68,69]. Such dependence on international prices raises greater concerns over energy security.

4.3. *Acceptability*

Acceptability is related to social and environmental implications in the electricity industry. Increased electricity consumption has subsequent impacts on the environment since CO_2 emissions are directly linked with electricity consumption and fuel mix in electricity generation [31].

Fig. 10 shows per capita CO_2 emissions from the electricity sector in the ASEAN-5 and the OECD during 1995–2007. Although CO_2

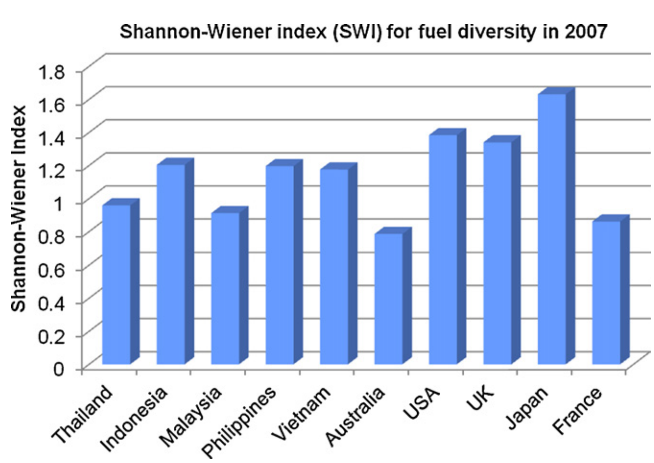

Fig. 9. Shannon–Wiener Index (SWI) in 2007.

Source: this study.

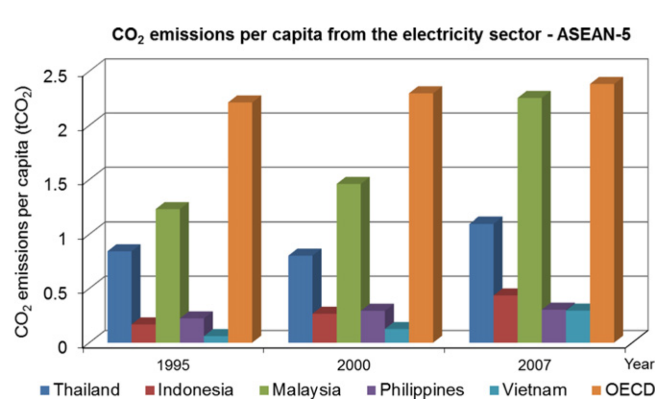

Fig. 10. CO_2 emissions per capita produced from the electricity sector during 1995–2007.

Data source: IEA [4].

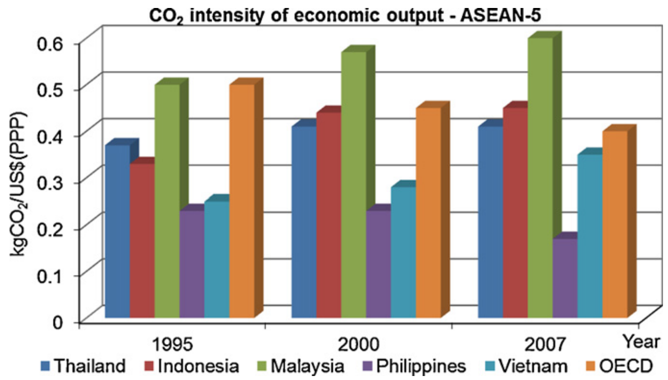

Fig. 11. CO_2 intensity of economic output during 1995–2007.
Data sources: IEA [4]; World Bank [26].

emissions per capita in these countries are still well below that of OECD average, the rate of increase is rather alarming. CO_2 emissions in these countries have increased between 100 and 300% over the past 20 years with Malaysia having per capital CO_2 emissions relatively close to that of OECD average by 2007. On the other hand, CO_2 emissions in the OECD have remained rather constant during this same period. However, the contribution of the ASEAN-5 to worldwide CO_2 emissions from the electricity sector is still relatively small. In 2009, the ASEAN-5 contributed approximately 2.5% of worldwide total CO_2 emissions from the electricity sector compared with 40% for the OECD and 30% for China [70].

There are also other factors that contribute to the level of CO_2 emissions from the electricity sector. These factors are country specific, and may include generating plants efficiency, percentage of electricity access and per capita income. This paper, though does not attempt to analyse the relationship among these factors. Rather, it looks at the trend of CO_2 emissions per capita from the electricity sector over time.

As shown in Fig. 11, CO_2 intensity in terms of economic output (CO_2/GDP) in these countries, except the Philippines, is increasing, which means that CO_2 emissions from the electricity sector have been increasing at a faster rate than economic growth. The ratio of CO_2 emissions per GDP responds to changes in electricity intensity [4], which has been previously shown to increase due largely to greater electricity access and structural shifts towards the industry sector.

CO_2 intensity of electricity generation (CO_2/kWh) in these five countries has fluctuated during 1995–2007, as shown in Fig. 12. The change in CO_2 intensity of electricity generation is related with the change in the structure of fuels used for electricity generation [12].

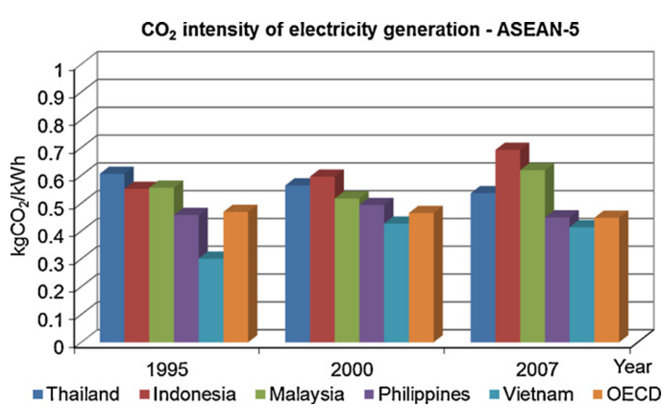

Fig. 12. CO_2 intensity of electricity generation during 1995–2007.
Data source: IEA [4]; World Bank [26].

Table 6
Nuclear power strategy in the ASEAN-5.

Country	Plans for nuclear power
Thailand	Plan for 2000 MW of nuclear power plants to be operated in 2020–2021.
Indonesia	Planned for 4 nuclear plants by 2025 but was cancelled due to tight credit and public opposition.
Malaysia	Express interest in the possible deployment of nuclear power after 2020 to diversity its fuel mix for electricity generation.
Philippines	Plan for 2400 MW of nuclear power during 2025–2034. Also contemplating reviving the Bataan nuclear plant, which was mothballed in 1986 to reduce fossil fuel dependence.
Vietnam	Plan to construct the first nuclear power plant, which is scheduled to commission in around 2017–2020.

Source: IEA [8].

This appears to be the case for the ASEAN-5 since the change in CO_2 intensity per kWh corresponds with the change in the share of coal in the fuel mix for electricity generation during the same period as shown in Fig. 7. For Thailand, the CO_2 intensity per kWh has been declining due to the shift of fuel mix from high emitting coal and oil sources to lower-emitting natural gas. For Indonesia, the CO_2 intensity per kWh is on a rising trend due to the increasing shares of coal in electricity generation. For Malaysia, the Philippines, and Vietnam, the fluctuations in CO_2 intensity per kWh also coincide with the fluctuation in the share of coal in electricity generation during the same period. The CO_2 intensity per kWh is considerably influenced by the share of high emission fuel sources such as coal in electricity generation.

Other than meeting domestic energy demand, the increasing pressure on greenhouse emissions, fossil fuel price volatility and the need to diversify fuel mix have led the governments in the ASEAN-5 countries to consider nuclear power as one of the options to solve such problems. Thailand, the Philippines and Vietnam have already included nuclear power as part of their future generation mix while Indonesia and Malaysia are contemplating this option [8,71]. Despite the keen interest in nuclear power by the governments in these countries, there are still considerable social and environmental acceptability implications – related to nuclear safety, waste management and nuclear proliferation – which need to be addressed. These concerns are yet to be formally addressed and the directions are still unclear, leading to an on-going debate on the necessity of nuclear power in the ASEAN-5 [38]. Therefore, a key challenge for these countries should they choose to try and deploy nuclear power lies in developing safety and security regulations in order to build the required social consensus and public acceptance that will be required. Table 6 summarises plans for nuclear power among these countries.

Renewable energy (RE) policy is also another important measure that can have a direct influence on electricity industry emissions. The ASEAN-5 countries have all noted the particular importance of RE as a measure to mitigate increasing CO_2 emissions as well as diversify fuel sources from fossil fuels in electricity generation. This is reflected by their RE policies and targets to promote renewable electricity generation. The ASEAN-5 countries provide financial incentives which include feed-in tariffs (FIT), tax exemptions and capital cost grants. RE targets and financial incentives provided by these countries are described in Table 7. Levels of ambitions and incentives as well as time frames vary among these countries, with Thailand, Indonesia and the Philippines appear to be very committed.

The main RE resources in this region consist of biomass, geothermal, mini and micro-hydro and solar energy. Estimated technical

Table 7
Renewable energy (RE) policies in the ASEAN-5.

Country	Renewable energy (RE) policy	
Thailand	Targets	• Increase the share of RE to 20% of total consumption by 2020 [72]. • Increase renewable generation capacity to 5.6 GW by 2022 mainly from Biomass. Other sources include wind, solar PV, and waste [71].
	Incentives	• FIT, tax holidays, import duty exemption, capital grants [72].
Indonesia	Targets	• Increase the share of renewable generating capacity of micro-hydro, geothermal, wind, solar PV, and biomass to 17% by 2030 [56].
	Incentives	• FIT and tax exemption for geothermal projects [28]
Malaysia	Targets	• Add 350 MW of grid connected renewable electricity by 2010 [58].
	Incentives	• FIT, tax holidays [28]. • Establish the Small RE Power Programme [8].
Philippines	Targets	• Increase RE capacity by 100% from the 2005 level by 2015 [28]. Adding 700 MW of new geothermal capacity during 2010–2014 [8].
	Incentives	• Taxes and duties exemption for geothermal power projects, FIT, capital grants [72].
Vietnam	Targets	• Add 4050 MW of renewable generation capacity including micro-hydro, wind, biomass, and solar PV by 2025 [28].
	Incentives	• FIT, Investment incentives, preferential pricing, and preferential taxes for development of new and RE resources [72].

Table 8
Technical potential for renewable electricity generation in the ASEAN-5.

RE resource	Combined technical potential	Countries	Remarks
Hydro	150 GW	All ASEAN-5 countries	• Includes mini- and micro-hydro potentials • >25% already exploited
Biomass	90 GW	All ASEAN-5 countries	• Fuels include agricultural and forestry residues, energy and forestry crops, animal residues, and municipal solid waste • Largely remains unexploited
Solar PV	4–7 $kWh/m^2/day$	All ASEAN-5 countries	Currently nearly non existent
Geothermal	30 GW	Indonesia and the Philippines	• Indonesia: 27 GW, the Philippines: 3 GW • Largely remains unexploited
Wind	180 GW	All ASEAN-5 countries	• Mainly in Vietnam and the Philippines • Include both on shore and off-shore

Source: [28,73].

Table 9
Share of renewable electricity generation in 2007.

Country	2007 share of non-hydro renewable electricity generation	2007 share of renewable electricity generation with hydro
Thailand	2.9%	8.6%
Indonesia	4.9%	12.9%
Malaysia	0	6.4%
Philippines	17.2%	31.6%
Vietnam	0	43%

potentials[6] for grid-connected renewable generation in the ASEAN-5 are summarised in Table 8. For off-grid applications, however, technical potentials are substantially larger and currently there is a relative high solar photovoltaic penetration for off-grid applications such as water pumping and lighting in Thailand, Indonesia, Philippines and Vietnam [8].

The ASEAN-5 has promising technical potentials for a range of RE resources. However, other than hydro, RE resources in the ASEAN-5 are currently underexploited due largely to economic and regulatory barriers [8]. Other barriers also include administrative hurdles, grid access issues, persistent fossil-fuel subsidies, and lack of information and training [28].

The share of renewable electricity generation with and without hydro of each country in 2007 is presented in Table 9. The Philippines have the highest share of non-hydro renewable generation capacity, which predominantly consists of geothermal, accounting for about 17% of total generation capacity. Malaysia and Vietnam, on the other hand, have negligible share of non-hydro renewable generation capacity whilst the share in Thailand and Indonesia is about 3% and 5%, respectively.

Social and environmental acceptability remains a challenging aspect for every country in the ASEAN-5 due largely to their rapidly increasing in CO_2 emissions. A sustainable level of CO_2 emissions is difficult to determine but avoiding dangerous climate change might require emissions to stabilise at levels equivalent to around 2 tCO_2/per-capita by 2050 [74]. Assuming that an effective and equitable international framework is established to address climate change, the rate of CO_2 emissions per capita growth and CO_2 intensity of economic output in the ASEAN-5 needs to be carefully addressed in order to improve environmental sustainability outcomes. Furthermore, although RE targets have been established for every country in the ASEAN-5, effective policy measures are required to overcome economic and regulatory barriers in order to increase the share of non-hydro renewable electricity generation.

5. Key challenges and options for electricity industries in the ASEAN-5

In this section, some of the key sustainability challenges for electricity industries in the ASEAN-5 are highlighted and contrasted. These challenges are also placed in the context of potential prioritisations among each aspect of the 3A's energy objectives for each country. Potential opportunities for collaboration among countries in this region to address these sustainability challenges are also considered.

[6] The technical potential is the amount of output obtainable by full implementation of technologies or practices on the basis of technical boundary conditions or technical limitations without explicit reference to costs, barriers, or policies [39]. The technical potential is dynamic and can be increased with improved technologies arising from R&D, demonstration and deployment [28].

5.1. Key sustainability challenges and options

In general, the electricity industries of the ASEAN-5 face increasing challenges in meeting rapid growth in electricity demand, improving both short-term quality of supply and longer-term energy security whilst reducing greenhouse emissions. The many specific challenges that will need to be overcome in order to ensure adequate and affordable access to electricity in an economic viable, socially and environmentally acceptable manner include:

- Ensuring sufficient generation and network capacity to improve the reliability of electricity supply whilst meeting growing demand. The utilities need to undertake timely and efficient investment to keep pace with the growth in demand. Improving electricity access in rural areas is a particular challenge for Indonesia, the Philippines and, to a lesser extent, Vietnam to facilitate economic and social development of these countries. Off grid RE applications may be of particular value in expanding rural electrification in countries with geographical barriers such as those of Indonesia and the Philippines.
- Managing tariff subsidies to address equity concerns while still enabling to appropriately develop and expand electricity infrastructure.
- Improving short-term quality of electricity supply in rural areas particularly in Thailand and Indonesia.
- Diversifying the industry fuel mix to enhance long term security of electricity supply by minimising risks arising from fossil fuel availability and price uncertainty, particularly in Thailand and Malaysia which have a heavy reliance on gas. Often the expansion of the local fuel supplies to reduce the amount of fuel imports can enhance security of supply but this may not address pricing impacts since fuel prices in this region are typically closely linked to international (traded) prices.
- Increasing the share of RE resources in electricity generation. This requires considerable policy support to fulfil their promising technical potential.
- Mitigating the rise in CO_2 emissions through RE and wider environmental policies to address environmental externalities. These include improved energy efficiency, appropriate regional development policies and the possible greater use of lower-emission fossil fuel options and nuclear power.
- Addressing social acceptability concerns regarding large power projects such as nuclear power and geothermal by improving governance arrangements through more transparent and inclusive decision making frameworks.

The challenges facing this region have some shared, yet also some different, priorities by comparison with both OECD members and the least developed countries. The WEC has recently argued [40] that access to modern energy and energy security are the two fundamental aspects that need to be addressed before considering higher order aspects including economic efficiency, social acceptability and environmental viability. In the context of this study, this suggests that the Accessibility and Availability aspects of the 3A's energy objectives should take higher priority than Acceptability for the ASEAN-5in particular. Although there appears to be growing concerns over environmental acceptability in this region, it can be argued that this concern should not be subjected to the same priority as improving electricity access and supply security. This is particularly the case for a global challenge such as climate change, given that per-capita emissions of the ASEAN-5 are generally far lower than those of the OECD countries, which also have far greater per-capita wealth. It therefore seems reasonable that improving electricity access should be a top priority particularly in countries like Indonesia, the Philippines and Vietnam where rural electrification rates are still relatively low. Enhancing energy security in both short-term and long-term should also be on the top of the agenda amongst the ASEAN-5. Some options to improve access and energy security are regional or national in nature. For example, there may be excellent opportunities for policy makers to facilitate greater energy efficiency and demand management – opportunities which have proven very valuable in some electricity industries around the world.

There would appear good options to address these sustainability challenges through regional collaboration in terms of resource sharing and integration amongst the ASEAN-5 electricity industries, and ASEAN in more general, since countries in this region have different natural resource endowments. The establishment of the ASEAN Power Grid and Trans-ASEAN Gas Pipeline have been identified as a key development in supporting increased resource sharing amongst the ASEAN countries [8,75].

Currently cross-border interconnections only exist amongst some ASEAN countries, and are far less developed than those of some other regions such as the European Union (EU) and the Nordic countries. The value of cross-border interconnections is that they can enhance the security of electricity supply over both the short and longer-term, as well as the efficiency of resource utilisation. There are complex and interrelated choices in terms of such cross-border interconnections – for example, pipelines or electricity transmission – and their specific characteristics. In terms of transmission, High Voltage Direct Current (HVDC) lines may be well suited to some applications for the ASEAN-5 including undersea links. HVDC links also have some advantageous operational characteristics for linking national systems with potentially different voltage and frequency requirements, and where a high degree of control is required. Greater interconnection of gas pipelines amongst ASEAN countries would also facilitate natural gas trading across their borders [8]. Such pipeline interconnections could increase reliability of both gas and electricity supply particular in countries which rely heavily on natural gas for electricity generation such as Thailand and Malaysia.

Other possible shared resources in this region are renewable resources including geothermal, hydro and biofuels [8,18]. Presently, there are agreements already in place between Laos PDR and its neighbouring countries including Thailand and Vietnam for the development of hydro trans-boundary projects under public–private partnership models. With their abundance of hydro resources but currently low domestic electricity demand, Laos can use these projects to sell electricity to its neighbours and therefore generate revenue that can be used towards reducing its poverty [39]. Furthermore, there are also potentials for these countries to learn from, and share experiences and information amongst one another on various issues such as the implementation of various policies and transfer of technologies.

Such collaborations could be important towards ensuring sustainable development of the electricity industries in ASEAN. Nevertheless there are many challenges to first overcome including a range of regulatory, policy and financial barriers, before such collaborations can be successfully established. This is particularly the case for the ones, which involve high costs such as cross-border interconnections and pipelines. Furthermore, common regulatory frameworks need to be established to ensure effective utilisation of cross-border interconnections and pipelines in a way that benefits every country in the region.

The collaboration in addressing sustainability in the electricity industry could build upon the existing ASEAN Plan of Action for Energy Cooperation (APAEC) [75]. Hopefully, sustainability assessments such as that undertaken in this study might provide a useful framework for better understanding the challenges and opportunities for such collaborations.

5.2. Implications for generation investment and planning in the ASEAN-5

The challenges outlined above have particularly significant implications for investment and resource planning in the ASEAN-5 electricity industries. Significant investment is required to just keep up with present electricity demand growth. It is predicted that the total investment in the power sector in the ASEAN region in the next 20 years could amount to $0.6 trillion despite the financial crisis [8]. Given the complex nature of generation and network investment which are generally capital intensive, long-lived, and have significant lead times, the industry must build ahead of time to meet uncertain and potentially highly variable future demand, whilst also factoring in other potential future drivers such as climate change. Investment decision making in the electricity industry is becoming increasingly challenging due to increased volatility and future uncertainty about fuel prices and availability, as well as growing concerns about climate change worldwide. High yet uncertain demand growth as seen in the ASEAN-5 countries adds to these challenges.

Efforts by many countries to address climate change are being based around establishing mechanisms and policies that put a price on CO_2 emissions. Serious efforts to address greenhouse emissions might require significantly greater investment in very different generation and network options to those otherwise likely to be deployed, and also have major impacts on demand growth [27]. Furthermore, with growing energy security concerns, there are good reasons to consider diversifying electricity fuel mixes in order to mitigate industry, and society, exposure to fuel price fluctuations and availability. Flexibility can strengthen sustainability outcomes, particularly in situations where future uncertainty has as great an influence as seen with the electricity industry [76]. Therefore, a well-diversified electricity generation portfolio which has an appropriate allowance for uncertainty would seem to offer significant benefits. Decision making processes in electricity generation investment, therefore, need to consider these factors. However, many key drivers are uncertain and likely correlated – for example plant capital costs, future fuel price, demand growth and environmental policy. Such challenges have added a new dimension to decision making processes in electricity industry investment. In addition to attempting to minimise overall future electricity industry costs, investment decision making needs to consider growing risks and uncertainties as well as environmental concerns.

Many of the existing decision support techniques for generation investment and planning do not explicitly taken into account key uncertainties noted earlier – future fuel price, plant capital costs, demand and possible environmental costs. Such techniques often focus on finding a least cost generation mix based on deterministic assumptions about future uncertainties. These techniques have been extended to incorporate some elements of uncertainty through scenario or sensitivity analysis. However, one key issue that need to be considered is that critical risk factors are highly uncertain and almost certainly correlated. Another key issue is the ability of the tools to better analyse potential trade-offs between expected future industry costs, and uncertainties in these costs.

Portfolio techniques offer frameworks that account for energy diversity and security which provide an analytic basis for policy makers to devise efficient generation portfolios that can enhance security and sustainability [77,78]. Such techniques also provide a basis for analysing cost and risk tradeoffs amongst different generation technology portfolios.

A novel generation investment decision support tool that formally incorporating incorporates this type of risk assessment as well as taking into consideration environmental sustainability concerns is currently being developed as part of the wider research programme to which this study has contributed [79].

6. Conclusions

Strong economic and social progress in fast developing countries such as those in ASEAN has driven substantial growth in electricity consumption. This increase in electricity consumption represents, in large part, highly desirable improvements in societal welfare. However, it is also leading to growing investment challenges as well as energy security concerns and increased CO_2 emissions due to the heavy reliance on fossil fuels for electricity generation in these countries. Therefore, it is essential that the electricity development is progressed in a manner that can manage potential conflicts between ensuring adequate and affordable electricity access with environmental concerns whilst taking advantage of potential synergies between these objectives.

This paper employs the 3A's energy sustainability objectives framework: Accessibility, Availability, Acceptability, together with some carefully selected indicators and criteria in the context of the electricity sector, to analyse key sustainability challenges for the electricity industries in Indonesia, Thailand, Malaysia, Vietnam and the Philippines. These ASEAN-5 countries possess some important similarities in terms of social and economic status as well as their progress towards more industrialised economies.

Although there are numerous challenges with data availability and consistency available from different agencies, this study still provides a coherent, largely quantitative, framework for exploring and contrasting the sustainability challenges for electricity industries within the ASEAN-5. The analysis highlights several key sustainability challenges as well as the current state of sustainability in electricity industries in the ASEAN-5. Although electricity access in these countries have remarkably improved over the past decades, there are many challenges that will need to be overcome in order to facilitate the growing demand in a sustainable manner. Key sustainability challenges in these countries include satisfying demand growth; enhancing security of supply through fuel diversification and RE resources; and mitigating the rapid increase in CO_2 emissions through effective RE policy. The analysis also suggests that there opportunities for the ASEAN countries to collaborate by sharing resources and experiences as well as learning from one another to improve sustainability in the electricity industries in these countries. These challenges are also considered to have important implications for generation investment and resource planning as these factors need to be taken into consideration during investment decision-making processes. This highlights a need and value for developing generation investment decision support tools that can better address these issues.

Appendix A.

Social and economic context indicators which have major implications for electricity industries in the ASEAN-5 countries are summarised in this section. These indicators for the ASEAN-5 are compared with Organisation for Economic Co-operation Development (OECD) average where applicable in order to highlight aspects of the stage of social and economic progress of the ASEAN-5 in relation with the so-called developed countries.

A.1. Social context

A.1.1. Population

The ASEAN-5 have a combined population of nearly 500 million people with Indonesia being the world's fourth most populous country [8,21]. Fig. A.1 shows populations among the ASEAN-5 between 1990 and 2008. During 1990–2008, populations in the ASEAN-5 countries have increased between 20 and 40% compared to 12% in the OECD. However the growth rates have slowed down

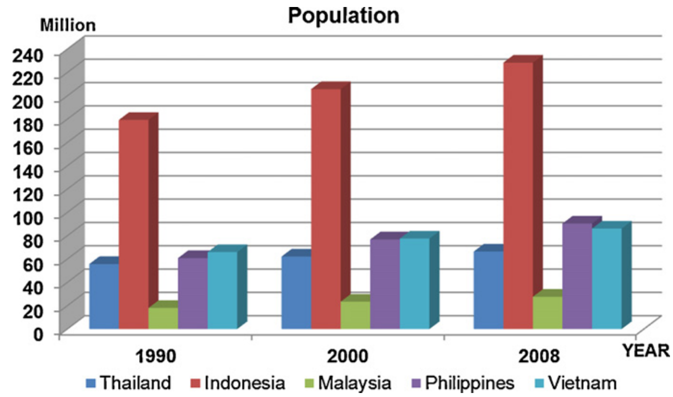

Fig. A.1. Population in the ASEAN-5.
Data source: ADB [21].

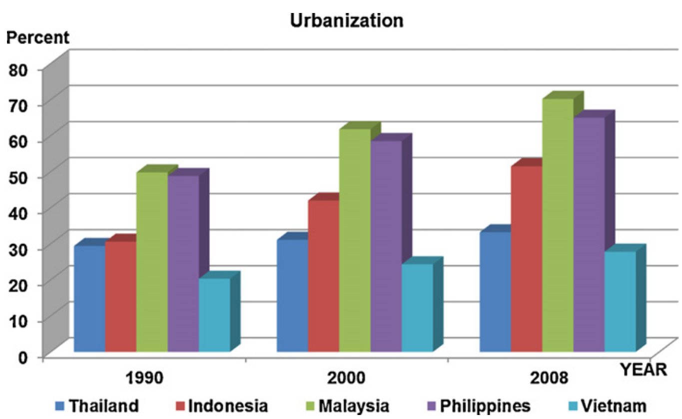

Fig. A.2. Urbanisation in the ASEAN-5.
Data source: ESCAP [80].

in recent years to about 2–3% per year compared to 0.5% per year in the OECD [21].

A.1.2. Urbanisation

As shown in Fig. A.2, urbanisation in these countries have also increased rapidly since 1990, but are still comparatively lower than the OECD where the urbanisation levels have been constantly high at about 70–80% throughout this period [22]. Generally the higher levels of urbanisation are among the more developed countries since levels of urbanisation in closely linked to economic growth where better economic opportunities and access to services in the cities attract migrants from rural areas [80].

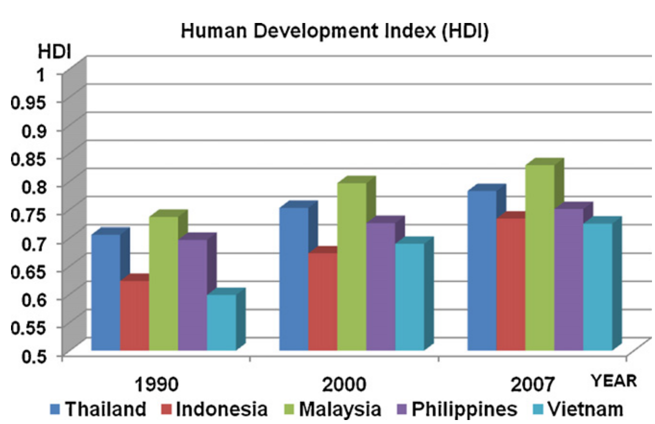

Fig. A.3. Human Development Index (HDI) during 1990–2007.

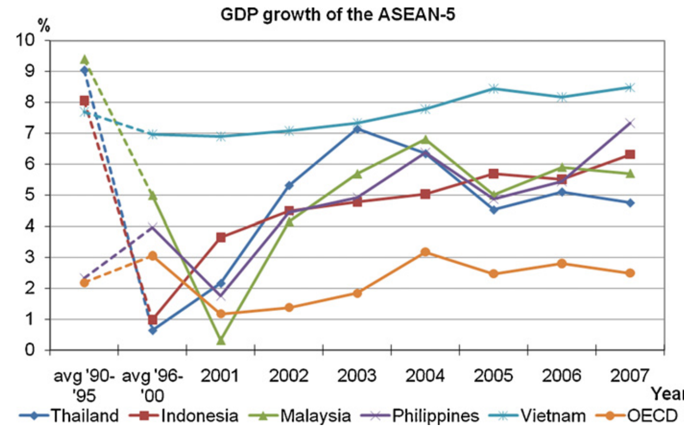

Fig. A.4. GDP growth rates in the ASEAN-5.
Data source: World Bank [26].

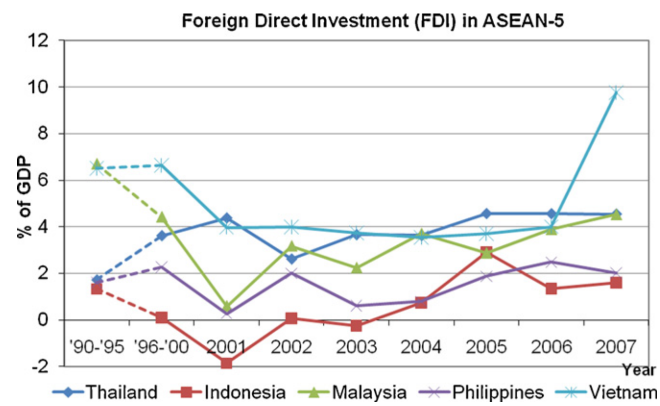

Fig. A.5. Foreign direct investment (FDI) in the ASEAN-5.
Data source: World Bank [26].

A.1.3. Human development

The Human Development Index (HDI) of countries in the ASEAN-5 is shown in Table A.1.

HDI in these countries has also been improving over the past two decades as shown in Fig. A.3, which implies improving human well-being and development.

A.2. Economic context

A.2.1. GDP growth

Countries in the ASEAN-5 have achieved robust economic growths over the past several decades due largely to the increase in

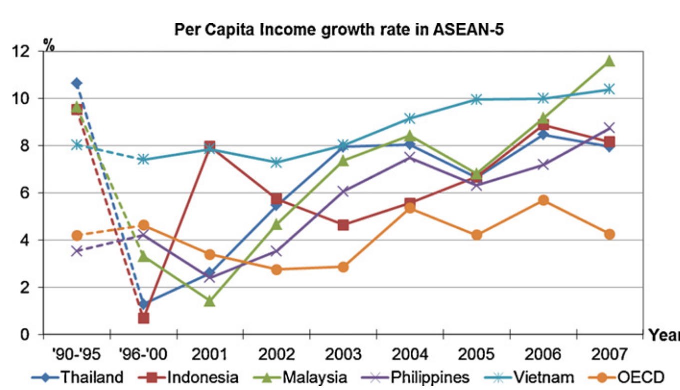

Fig. A.6. Per capita income growth rate in the ASEAN-5.
Data source: World Bank [26].

Table A.1
HDI index and ranking of ASEAN-5.

Country	HDI in 2007	HDI rank (from 182 countries)	Classification
Thailand	0.783	87	Medium
Indonesia	0.734	111	Medium
Malaysia	0.829	66	High
Philippines	0.751	105	Medium
Vietnam	0.725	116	Medium

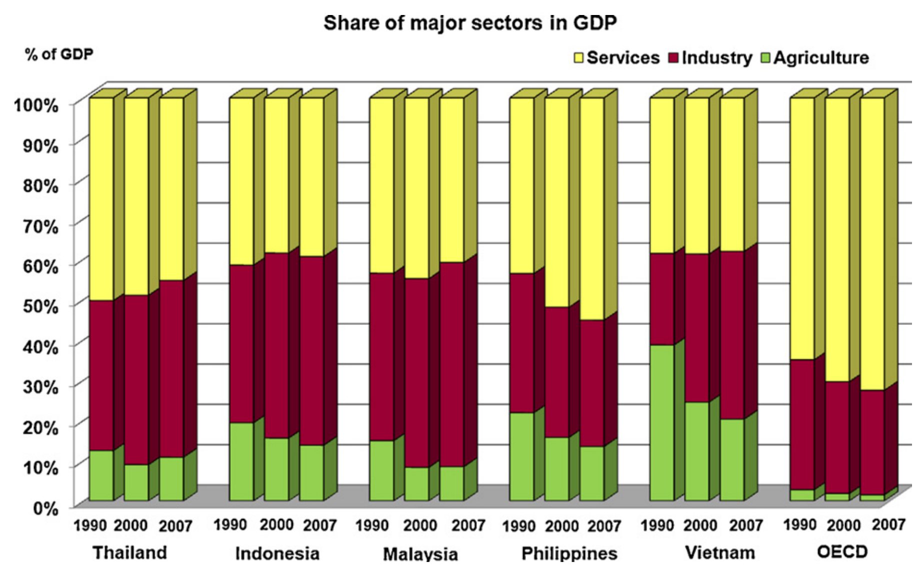

Fig. A.7. Share of major sectors in GDP during 1990–2007.

Data source: World Bank [26].

trade and foreign investment [24]. Fig. A.4 shows the GDP growth rate of the ASEAN-5 during 1900–2007 compared with that of the OECD.

After the Asian economic crisis in the late 1990s, these five countries have been able to maintain economic growth at the rate between 4 and 8% with Vietnam achieving the highest growth of around 8% over the past 20 years. With the exception of Indonesia, the global financial crisis in 2008 has restricted economic growth in these countries during the past years.

A.2.2. Foreign Direct Investment (FDI)

Fig. A.5 shows the amount of Foreign Direct Investment (FDI) as a percentage of GDP in these five members of ASEAN since 1990. The amount of FDI in Vietnam has significantly increased over the past few years, reaching about 11% of GDP in 2008. For Thailand and Malaysia, the amount of FDI has been fairly consistent at around 4% of GDP for the last decade. Indonesia and the Philippines have the lowest FDI of around 2% of GDP.

A.2.3. Per capita income growth

Per capita income growth rate in ASEAN-5 is on a rising trend, as shown in Fig. A.6, reaching the growth of between 8 and 11% in 2007, which is higher than the growth of 4 and 6% average attained in the OECD. The increase in per capita income is a useful if incomplete measure of the development of standard of living of people. Rising per capita income also generally means a growing middle class with higher spending power [81].

A.2.4. Share of sectoral value added to GDP

The proportion of sectoral valued added to GDP of the ASEAN-5 and the OECD during 1990–2007 are shown in Fig. A.7. The share of GDP in industry sector is another factor that can be used to assess the progress of industrialisation.

Other than the Philippines, the trend of industry sector value added has been increasing since 1990 at the expense of agriculture and service sectors. This is in contrast with OECD countries since their share of industry sector value added in GDP has decreased from 32% in 1990 to 25% in 2007. The share of GDP from the industry sector in 2007 for every country, except the Philippines, is accounted for more than 40% of the total GDP whereas in the OECD, industry valued added is accounted for only about 25% of total GDP. The share of service sector value added in the OECD predominantly contributes to the overall GDP, which is about 70% in 2007.

References

[1] WCED. Our common future: the Brundtland report. World Commission on Environment and Development; 1987.
[2] Hasna AM. Dimensions of sustainability. Journal of Engineering for Sustainable Development: Energy, Environment, and Health 2007;2(1):47–57.
[3] Najam A, Cutler J, Energy, Sustainable. Development at global environmental summits: an evolving agenda. Environment, Development and Sustainability 2003;5:117–38.
[4] IEA. CO_2 emissions from fuel combustion, 2009 edition. Paris: International Energy Agency; 2009.
[5] Kemmler A, Spreng D. Energy indicators for tracking sustainability in developing countries. Energy Policy 2007;35(4):2466–80.
[6] ADB. Key indicators for Asia and the Pacific 2010. 41st edition Asian Development Bank; 2010.
[7] WEC. Delivering sustainability: challenges and opportunities for the energy industry. London: World Energy Council Statement; 2005.
[8] IEA. World energy outlook 2009. Paris: International Energy Agency; 2009.
[9] Tsai WT. Energy sustainability from analysis of sustainable development indicators: a case study in Taiwan. Renewable and Sustainable Energy Reviews 2010;14(7):2131–8.
[10] Schaeffer R, Szklo AS, Cima FM, Machado G. Indicators for sustainable energy development: Brazil's case study. Natural Resources Forum 2005;29(4):284–97.
[11] Streimikiene D. Monitoring of energy supply sustainability in the Baltic Sea region. Energy Policy 2007;35(3):1658–74.
[12] Streimikiene D, Ciegis R, Grundey D. Energy indicators for sustainable development in Baltic States. Renewable and Sustainable Energy Reviews 2007;11(5):877–93.

[13] Taylor PG, Wiesenthal T, Mourelatou A. Energy and environment in the European Union: an indicator-based analysis. Natural Resources Forum 2005;29(4):360–76.
[14] IAEA/UNDESA. Energy indicators for sustainable development: countries studies on Brazil, Cuba, Lithuania, Mexico, Russian Federation, Slovakia and Thailand. Vienna: International Atomic Energy Agency; 2005.
[15] Neves AR, Leal V. Energy sustainability indicators for local energy planning: review of current practices and derivation of a new framework. Renewable and Sustainable Energy Reviews 2010;14(9):2723–35.
[16] Evans A, Strezov V, Evans TJ. Assessment of sustainability indicators for renewable energy technologies. Renewable and Sustainable Energy Reviews 2009;13(5):1082–8.
[17] Onat N, Bayar H. The sustainability indicators of power production systems. Renewable and Sustainable Energy Reviews 2010;14(9):3108–15.
[18] Karki SK, Mann MD, Salehfar H. Energy and environment in the ASEAN: challenges and opportunities. Energy Policy 2005;33(4):499–509.
[19] Jafar AH, Al-Amin AQ, Siwar C. Environmental impact of alternative fuel mix in electricity generation in Malaysia. Renewable Energy 2008;33(10):2229–35.
[20] IEA. Energy statistics for non-OECD countries 2010 edition. Paris: International Energy Agency; 2010.
[21] ADB. Key indicators for Asia and the Pacific 2009. 40th edition Asian Development Bank; 2009.
[22] UNDP. Human development report 2009 – overcoming barriers: human mobility and development. New York: United Nations Development Programme; 2009.
[23] Pasternak A. Global energy futures and human development: a framework for analysis. Lawrence Livermore National Laboratory; 2000.
[24] IMF. World economic outlook 2010: rebalancing growth. International Monetary Fund; 2010.
[25] ADB. Key indicators for Asia and the Pacific 2008. Asian Development Bank; 2008.
[26] World Bank. World bank indicators for various years. The World Bank; 2011 [Online] http://databank.worldbank.org/ddp/home.do [accessed July 2011].
[27] IEA. World energy investment outlook. Paris: International Energy Agency; 2003.
[28] Ölz S, Beerepoot M. Deploying renewables in Southeast Asia: trends and potential working paper. Paris: International Energy Agency; 2010. Available at http://dx.doi.org/10.1787/5kmd4xs1jtmr-en.
[29] EIA. Independent statistics and analysis for various years: energy information administration; 2010, http://www.eia.doe.gov/fuelelectric.html.
[30] WEC. A report on the world energy congress 2010. London: World Energy Council; 2010, http://www.worldenergy.org/documents/congressreview_hkhatib.pdf.
[31] WEC. Deciding the future: energy policy scenarios to 2050. London: World Energy Council; 2007, http://www.worldenergy.org.
[32] Wamukonya N. Power sector reform in developing countries: mismatched agendas. Energy Policy 2003;31(12):1273–89.
[33] WEC. Energy for tomorrow's world – acting now. London: World Energy Council Statement; 2000.
[34] Bazilian M, Hobbs BF, Blyth W, MacGill I, Howells M. Interactions between energy security and climate change: a focus on developing countries. Energy Policy 2011;39(6):3750–6.
[35] IEA. Security of supply in electricity market: evidence and policy issues. Paris: International Energy Agency; 2002.
[36] Foster V, Briceño-Garmendia C. Africa's infrastructure: a time for transformation. Washington, DC: The International Bank for Reconstruction and Development/The World Bank; 2010.
[37] Sundqvist G, Elam M. Public involvement designed to circumvent public concern? The "Participatory Turn" in European nuclear activities. Risk, Hazards & Crisis in Public Policy 2010;1(4):203–29.
[38] IAEA. Climate change and nuclear power. Vienna: International Atomic Energy Agency; 2009.
[39] IPCC. Special report on renewable energy sources and climate change mitigation. New York: The Intergovernmental Panel on Climate Change (IPCC); 2011, http://srren.ipcc-wg3.de/report/IPCC_SRREN_Full_Report.pdf.
[40] WEC. Global energy: agenda, challenges, policies. In: Presentation at 12th International Energy Forum. 2010.
[41] IAEA. Energy indicators for sustainable development: guidelines and methodologies. Vienna: International Atomic Energy Agency; 2005.
[42] Vera I, Langlois L. Energy indicators for sustainable development. Energy 2007;32(6):875–82.
[43] Chang Y, Lee JL. Electricity market deregulation and energy security: a study of the UK and Singapore electricity markets. International Journal of Global Energy Issues 2008;29(1–2):109–32.
[44] Eto J, LaCommare K. Tracking the reliability of the U.S. electric power system: an assessment of publicly available information reported to state public utility commissions. Ernest Orlando Lawrence Berkeley National Laboratory; 2008.
[45] NERC. Special reliability scenario assessment: potential reliability impacts of swift demand growth after a long-term recession. Princeton: North American Electricity Reliability Corporation; 2010.
[46] IEA. Security of supply in electricity markets: evidence and policy issues. Paris: International Energy Agency; 2002.
[47] Grubb M, Butler L, Twomey P. Diversity and security in UK electricity generation: the influence of low-carbon objectives. Energy Policy 2006;34(18): 4050–62.
[48] Stirling A. Diversity and ignorance in electricity supply investment: addressing the solution rather than the problem. Energy Policy 1994;22(3):195–216.
[49] IEA. Fossil fuel-fired power generation: case studies of recently constructed coal and gas-fired power plants. Paris: International Energy Agency; 2007.
[50] ASEAN Secretariat. ASEAN Environment. Jakarta: The ASEAN Secretariat; 2011.
[51] IEA. Energy technology perspectives 2008: scenario & strategies to 2050. Paris: International Energy Agency; 2008.
[52] IEA. World energy outlook 2011. Paris: International Energy Agency; 2011.
[53] IEA. CO_2 capture and storage: a key carbon abatement option. Paris: International Energy Agency; 2008.
[54] ASEAN Centre for Energy. ASEAN electricity tariff; 2010.
[55] IEA. Energy prices and taxes quarterly statistics: third quarter 2010. Paris: International Energy Agency; 2010.
[56] IEA. Energy policy review of Indonesia. Paris: International Energy Agency; 2008.
[57] EGAT. Electricity generating authority of Thailand annual report 2008. Electricity Generating Authority of Thailand; 2008. Available at http://pr.egat.co.th/AnnualReport/annual2008/annual08_eng/index_eng.html.
[58] Tenaga Nasional Berhad (TNB). Tenaga Nasional Berhad annual report 2009. Malaysia: Tenaga Nasional Berhad; 2009.
[59] ADB. Progress of Vietnam power development and transmission interconnection projects. In: Presented at the Greater Mekong subregion 7th meeting of the Planning Working Group (PWG-7). 2009.
[60] The Association of the Electricity Supply Industry of East Asia and the Western Pacific (AESIEAP). AESIEAP gold book 2009. Singapore: The Association of the Electricity Supply Industry of East Asia and the Western Pacific; 2009.
[61] Metropolitan Electricity Authority (MEA). Metropolitan electricity authority annual report 2008. Bangkok: Metropolitan Electricity Authority; 2008.
[62] Provincial Electricity Authority (PEA). Provincial electricity authority annual report 2008. Bangkok: Provincial Electricity Authority; 2008.
[63] ADB. Report and recommendation on proposed loan and administration of loan and grant republic of Indonesia: Java-Bali electricity distribution performance improvement project. Asian Development Bank; 2010.
[64] The Japan Economic Research Institute. The Philippines Luzon grid transmission project associated with private power project. The Japan Economic Research Institute; 2007, http://www.jica.go.jp/english/operations/evaluation/oda_loan/post/2007/pdf/project13_full.pdf.
[65] Short TA. Electric power distribution handbook. London: CRC Press; 2004.
[66] IEEE. IEEE standard 1366–2003: IEEEE guide for electric power distribution reliability indices. The Institute of Electrical and Electronics Engineers; 2003.
[67] IEA. Electricity information 2009. Paris: International Energy Agency; 2009.
[68] Nakawiro T, Bhattacharyya SC. High gas dependence for power generation in Thailand: the vulnerability analysis. Energy Policy 2007;35(6): 3335–46.
[69] Asia Pacific Energy Research Centre. APEC energy pricing practices: natural gas end-use price. Tokyo: Asia Pacific Energy Research Centre; 2001.
[70] IEA. CO_2 emissions by product and flow: IEA CO_2 emissions from fuel combustion statistics (database); 2010, http://dx.doi.org/10.1787/data-00430-en [accessed 20.12.11].
[71] EGAT. Summary of Thailand power development plan 2010–2030. Electricity Generating Authority of Thailand; 2010.
[72] REN21. Renewables 2010 global status report: renewable energy policy network for the 21st century. World Watch Institute; 2010.
[73] Lidula NWA, Mithulananthan N, Ongsakul W, Widjaya C, Henson R. ASEAN towards clean and sustainable energy: potentials, utilization and barriers. Renewable Energy 2007;32(9):1441–52.
[74] Garnaut R. *The Garnaut Climate Change Review: Final Report*. Melbourne. http://www.garnautreview.org.au; 2008.
[75] ASEAN Ministers on Energy Meeting (AMEM). *ASEAN Plan of Action for Energy Cooperation 2004–2009*. Manila, Philippines, June. http://www.aseansec.org/; 2004.
[76] Steen N. Sustainable development and the energy industries. London: Earthscan Publications Ltd.; 1994.
[77] Awerbuch S. Portfolio-based electricity generation planning: policy implications for renewables and energy security. Mitigation and Adaptation Strategies for Global Change 2006;11(3):693–710.
[78] Bazilian M, Roques FA. Using portfolio theory to value power generation investments. In: Bazilian M, Roques FA, editors. Analytical methods for energy diversity and security: a tribute to Shimon Awerbuch. London: Elsevier; 2008. p. 61–8.
[79] Vithayasrichareon P, MacGill IF. A Monte Carlo based decision-support tool for assessing generation portfolios in future carbon constrained electricity industries. Energy Policy 2012;41(0):374–92.
[80] ESCAP. Statistical for Asia and the Pacific 2009. United Nations Economic and Social Commission for Asia and the Pacific; 2009.
[81] Deutsche Bank Research. ASEAN-5: a visual essay. Frankfurt: Deutsche Bank Research; 2006.